APPLICATION

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TITLE: DUAL-MODE TRANSCEIVER FOR INDOOR AND OUTDOOR ULTRA WIDEBAND COMMUNICATIONS

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DUAL-MODE TRANSCEIVER FOR INDOOR AND OUTDOOR ULTRA WIDEBAND COMMUNICATIONS

Background

This invention is generally relative to short-range wireless ultra wideband communications (UWB) for indoor and outdoor operation.

On April 22, 2002, U.S. Federal Communications Commission (FCC) released the revision of Part 15 of the Commission's rules regarding UWB transmission systems to permit the marketing and operation of certain types of new products incorporating UWB technology. With appropriate technology, UWB device can operate using spectrum occupied by existing radio service without causing interference, thereby permitting scare spectrum resources to be used more efficiently. It has been believed that UWB technology offers significant benefits for Government, public safety, businesses and consumers under an unlicensed basis of operation spectrum.

UWB device can be classified in three types based on the operating restrictions: (1) imaging system including ground penetrating radars and wall, through-wall, surveillance, and medical imaging device, (2) vehicular radar systems, and (3) communications and measurement systems. In general, FCC is adapting unwanted emission limits for UWB device that are significantly more stringent than those imposed on other Part 15 devices. In other words, FCC limits outdoor use of UWB device to imaging

systems, vehicular radar systems and hand held devices. Limiting the frequency bands, which is based on the -10 dB bandwidth of the UWB emission, within certain UWB products will be permitted to operate. For communications and measurement systems, FCC provides a wide variety of UWB devices, such as high-speed home and business networking devices as well as storage tank measurement devices under Part 15 of the Commission's rules subject to certain frequency and power limitations. The device must operate in the frequency band from 3.1 GHz to 10.6 GHz. UWB communication devices should also satisfy by the Part 15.209 limit, which sets emission limits for indoor and outdoor UWB system, for the frequency band below 960 MHz and conform the FCC's emission masks for the frequency band above 960 MHz.

For the indoor UWB communication operation, Table 1 lists the FCC restrictions of the emission masks (dBm) along with the frequencies (GHz).

Table 1

Frequency (MHz)	EIRP (dBm)
0-960	-41.3
960-1610	-75.3
1610-1990	-53.3
1990-3100	-51.3
3100-10600	-41.3
Above 10600	-51.3

The outdoor handheld UWB communication systems are intended to operate in a peer-to-peer mode without restriction on location. However, the handheld UWB device must operate in the frequency band from 3.1 GHz to 10.6 GHz, with an extremely conservative out of band emission masks to address interference with other communication devices. The outdoor handheld UWB communication devices are permitted to emit at or below the Part 15.209 limit in the frequency band below 960 MHz. The emissions above 960 MHz must conform to the following emission masks as shown in Table 2:

Table 2

Frequency (MHz)	EIRP (dBm)
0-960	-41.3
960-1610	-75.3
1610-1900	-63.3
1900-3100	-61.3
3100-10600	-41.3
Above 10600	-61.3

FCC proposed to define a UWB device as any device where the fractional bandwidth is greater than 0.25 based on the formula as follows,

$$FB = 2\left(\frac{f_H - f_L}{f_H + f_L}\right), \qquad (1)$$

where f_H is the upper frequency of the -10 dB emission point and f_L is the lower frequency of the -10 dB emission point. The center frequency of the transmission was defined as the average of the upper and lower -10 dB points. That is

$$F_C = \frac{f_H - f_L}{2}. \tag{2}$$

In addition, a minimum bandwidth of 500 MHz must be used for indoor and outdoor UWB devices regardless of center frequency.

The UWB communication devices must be designed to ensure that operation can only occur indoor according to indoor emission masks in Table 1 or it must consist of hand-held devices that may be employed for such activities as peer-to-peer operation according to the outdoor emission masks in Table 2. Such UWB devices can be used for wireless communications, particularly for short-range high-speed data transmissions suitable for broadband access to networks.

Since the indoor and outdoor UWB communication devices may have similar structures and operation functions, designing a dual-mode UWB communication device with ability of using in the indoor and outdoor operation is crucial. This leads to save the cost for the UWB communication transceiver. However, the dual-mode indoor and outdoor UWB communication transceiver needs to have different transmission and receiver filters, which are key elements

to make such UWB transceiver successfully, because the dual-mode indoor and outdoor UWB communication transceivers have to meet the different masks of the FCC emission limitation for indoor and outdoor operations.

Thus, there is a continuing need for a dual-mode UWB communication transceiver with employing dual-mode architecture of digital transmission shaping filters and receiver filters for the indoor and outdoor operations.

Brief Description of the Drawings

FIG. 1 shows a block diagram of one embodiment of a dual-mode UWB communication transceiver for the indoor and outdoor operation in accordance with the present invention.

FIG. 2 is a block diagram of showing a dual-mode UWB communication transmitter for the indoor and outdoor operation according to some embodiments.

FIG. 3 is a transmitter spectrum mark of the indoor power spectrum density (dBm) according to some embodiments.

FIG. 4 is a transmitter spectrum mark of the outdoor power spectrum density (dBm) according to some embodiments.

FIG. 5 is a block diagram of showing one embodiment of a dual-mode digital transmission shaping filters of the present invention.

FIG. 6 is an enlarged transmitter spectrum mark of the indoor power spectrum density (dBm) according to some embodiments.

FIG. 7 is a frequency and impulse response of digital enlarged transmission shaping filter for the indoor operation according to one embodiment.

FIG. 8 is a frequency response of a multiband digital transmitter shaping FIR filter for the indoor operation according to one embodiment.

FIG. 9 is an enlarged transmitter spectrum mark of the outdoor power spectrum density (dBm) according to some embodiments.

FIG. 10 is a frequency and impulse response of digital enlarged transmission shaping filter for the outdoor operation according to one embodiment.

FIG. 11 is a frequency response of a multiband digital transmitter shaping FIR filter for the outdoor operation according to one embodiment.

FIG. 12 is a rejected transmitter image spectrum mark of the use in both indoor and outdoor operation according to some embodiments.

FIG. 13 is a frequency and impulse response of digital rejected transmitter image filter according to one embodiment.

FIG. 14 is a frequency response of cascading the indoor multiband digital transmitter shaping FIR filter and the digital rejected transmitter image filter according to one embodiment.

FIG. 15 is a frequency response of cascading the outdoor multiband digital transmitter shaping FIR filter and the digital rejected transmitter image filter according to one embodiment.

FIG. 16 is a frequency spectrum including 11 transmitter channel spectrums for the indoor operation along with the indoor FCC emission mask limitation according to some embodiments.

FIG. 17 is a frequency spectrum including 11 transmitter channel spectrums for the outdoor operation along with the outdoor FCC emission mask limitation according to some embodiments.

FIG. 18 is a block diagram of showing dual-mode architecture of the digital transmitter-shaping FIR filter for the indoor and outdoor operation according to some embodiments.

FIG. 19 is a block diagram of showing a pre-addition architecture for the use in the dual-mode digital transmitter-shaping filter with the indoor and outdoor operation according to some embodiments.

FIG. 20 is a block diagram of showing memory structures of containing the transmission filter coefficients and input samples.

FIG. 21 is a block diagram of showing a dual-mode UWB communication receiver for the indoor and outdoor operation according to some embodiments.

FIG. 22 is a block diagram of showing one embodiment of dual-mode digital receiver filters of the present invention..

FIG. 23 is a receiver spectrum mark of the indoor power spectrum density (dBm) according to some embodiments.

FIG. 24 is a frequency and impulse response of the indoor digital receiver filter according to one embodiment.

FIG. 25 is a receiver spectrum mark of the outdoor power spectrum density (dBm) according to some embodiments.

FIG. 26 is a frequency and impulse response of the outdoor digital receiver filter according to one embodiment.

FIG. 27 is a block diagram of showing dual-mode architecture of the digital receiver filter for the indoor and outdoor operation according to some embodiments.

FIG. 28 is a block diagram of showing a pre-addition architecture for the use in dual-mode digital receiver filter according to some embodiments.

FIG. 29 is a block diagram of showing memory structures of containing the receiver filter coefficients and input samples according to some embodiments.

FIG. 30 is a block diagram of showing a flowchart of implementing a dual-mode UWB transceiver for the indoor and outdoor operation according to some embodiments.

Detailed Description

Some embodiments described herein are directed to the dual-mode UWB communication transceiver of the indoor and outdoor operation. The dual-mode UWB communication transceiver may be implemented in hardware, such as in an Application Specific Integrated Circuits (ASIC), digital signal processor, field programmable gate array (FPGA), software, or a combination of hardware and software.

FIG. 1 illustrates a dual-mode UWB communication transceiver 100 for indoor and outdoor operation in accordance with one embodiment of the present invention. This dual-mode UWB transceiver 100 includes an indoor or outdoor UWB multi-carrier and multichannel RF section 114 that receives and/or transmits multichannel UWB signals from an antenna 112 or to an antenna 110. The section 114 is connected with an analog and digital interface section 116 that contains A/D and D/A converters. The interface section 116 is coupled to an indoor and outdoor digital baseband processing section 118, which performs multichannel digital transmission and receiver filtering, rake processing, spread/de-spread processing, interleave/de-interleave, and code/de-code processing. The digital baseband processing section 118 has an interface with a UWB network interface section 120 in which is coupled to a UWB network 122. In accordance with one embodiment of the present invention, the UWB transceiver

100 is a so-called dual-mode UWB communication transceiver of indoor and outdoor operation that can both transmit and receive speech, audio, images and video and data information for the indoor and/or outdoor wireless broadband communications.

The dual-mode UWB communication transceiver 100 of the indoor and outdoor operation can transmit and/or receive the UWB signals by using one channel and/or up to 11 channels in parallel. Each channel of the UWB system 100 has a frequency bandwidth of 650 MHz that can transmit 40.625 Msps. That is, a total of 11 channels are able to transmit 446.875 Msps. The UWB transceiver 100 also employs the orthogonal spread codes for all the channels. With 16 PN spread sequence codes for each symbol, each channel achieves 650 Mcps. As a result, the dual-mode UWB communication transceiver 100 of the indoor and outdoor operation can transmit and/or receive the chip data rate up to 7.150 Gcps.

FIG. 2 is the block diagram of showing a dual-mode UWB communication transmitter 200 for indoor and outdoor operation according to some embodiments. The dual-mode UWB communication transmitter 200 receives user data bits 210 with information data rate at 223.4375 Mbps. The information data bits 210 are passed through a 1/2-rate convolution encoder 212 that may produce the double data rate of 446.875 Msps by adding redundancy bits. The symbol

data is then interleaved by using a block interleaver 214. Thus, the output symbols of the block interleaver 214 are formed 11-multichannel by using a multichannel PN sequence mapping 218. The symbol data rate of each channel is about 40.625 Msps. The multichannel PN sequence mapping 218 is to perform spreading for one symbol data with 16 orthogonal spread sequence chips and to produce 650 Mcps for each channel under a multichannel control 230. A PN sequence look-up table 216 provides the unique orthogonal sequences for each channel spreading. Then chip data of each channel is sequentially passed through an indoor or outdoor dual-mode digital FIR lowpass shaping filters 220 to limit the frequency bandwidth with 650 MHz for each channel signal. Each channel signal is passed through a D/A converter 222. The output chip data of each channel from the D/A converter 222 is then modulated with a multi-carrier by using a multichannel based multi-carrier modulator 224. The clock control 228 is used to control the dual-mode digital FIR lowpass shaping filter 220, the D/A converter 222, and the multichannel-based multi-carrier modulator 224. Thus, the output analog signals of the multichannel-based multi-carrier modulator 224 are passed the power amplifier (PA) 226 through an antenna into air.

FIG. 3 is a transmitter spectrum mark 320 of the indoor power spectral density 300 for each channel according to some embodiments. The magnitudes (dBm) of the

frequency response with an error of $\pm\delta_i$ (i = 1,2,3,4) for corresponding frequencies (GHz) are given by,

$$(-41.4-\delta_1)\le|H(f)|\le(-41.4+\delta_1)\,,\quad |f-f_c|\le 0.26\,, \tag{3}$$

$$|H(f)|\le(-51.8+\delta_2)\,,\quad |f-f_c|=0.325\,, \tag{4}$$

$$|H(f)|\le(-54.3+\delta_3)\,,\quad |f-f_c|=0.39\,, \tag{5}$$

$$|H(f)|\le(-76.8+\delta_4)\,,\quad 0.45\le|f-f_c|\le 0.5\,. \tag{6}$$

The transmitter spectrum mark 320 serves as a rule for designing a digital FIR lowpass-shaping transmitter for the indoor UWB transceiver.

FIG. 4 is a transmitter spectrum mark 420 of the outdoor power spectral density 400 for the use in the each channel transmitter filter according to some embodiments. The magnitudes (dBm) of the frequency response with an error of $\pm\delta_i$ (i = 1,2,3,4) for corresponding frequencies (GHz) are given by,

$$(-41.8-\delta_1)\le|H(f)|\le(-41.8+\delta_1)\,,\quad |f-f_c|\le 0.26\,, \tag{3}$$

$$|H(f)|\le(-61.8+\delta_2)\,,\quad |f-f_c|=0.325\,, \tag{4}$$

$$|H(f)|\le(-63.8+\delta_3)\,,\quad |f-f_c|=0.39\,, \tag{5}$$

$$|H(f)|\le(-75.8+\delta_4)\,,\quad 0.45\le|f-f_c|\le 0.5\,. \tag{6}$$

The transmitter spectrum mark 420 serves as a rule of designing a digital FIR lowpass-shaping transmitter for the outdoor UWB transceiver.

A direct design of the indoor and outdoor transmitter filter based on the indoor transmitter spectrum mask 320 and the outdoor transmitter spectrum mask 420 will lead to a huge number of filter taps. In order to reduce the number of filter taps for the digital transmitter shaping filters for the indoor and outdoor UWB transceiver 200, an efficient design method 500 of the cascaded filters may be used as shown in FIG. 5. The cascaded filters are met the requirement of the indoor transmitter spectrum mask 320 and the outdoor transmitter spectrum mask 420 while the filter taps can be significantly reduced.

Referring to FIG. 5 is a block diagram of showing a dual-mode digital FIR lowpass-shaping transmitter filter 500 for the indoor and outdoor UWB transceiver according to some embodiments. During the indoor UWB transmitter mode, a switch 512 is connected to a position 510A and a switch 520 is connected with a position 518A. In this case, the indoor UWB enlarged band digital FIR filter 514 is cascaded with the UWB digital rejected FIR filter 522. The combination of the digital enlarged band digital FIR filter 514 and the digital rejected FIR filter 522 can achieve the transmitter function that meet the transmitter spectrum mask 320 of the indoor power spectrum density 300 in FIG. 3. On the other hand, during the outdoor UWB transmitter mode, the switch 512 is connected to a position 510B and the switch 520 is connected with a position 518B. In this case, the outdoor

UWB enlarged band digital filter 516 is cascaded with the UWB digital rejected FIR filter 522. The combination of the digital enlarged band FIR filter 516 and the digital rejected FIR filter 522 can achieve the transmitter function that meets the transmitter spectrum mask 420 of the outdoor power spectrum density 400 as shown in FIG. 4.

The common UWB digital rejected FIR filter 522 as shown in FIG. 5 contains an even filter with even taps 524A and an odd filter with odd taps 524B. The switch 528 is connected with the position 526A (when $n = 0, 2, 4, \ldots$) and is connected with the position 526B (when $n = 1, 3, 5, \ldots$). Thus, the even filter 524A and the odd filter 524B operate in parallel. This is polyphase implementation for the interpolation filter with up sampling by 2.

Referring to FIG. 6, which is an enlarged transmitter spectrum mark 620 of the indoor power spectral density 600 for the use of the indoor enlarged digital lowpass shaping FIR filter 514 of FIG. 5 according to some embodiments. The enlarged transmitter spectrum mark 620 is a double frequency bandwidth of the transmitter spectrum mask 320 of the indoor power spectrum density 300 as shown in FIG. 3. The magnitudes (dBm) of the frequency response of the enlarged transmitter filter with an error of $\pm\delta_i$ ($i = 1,2,3,4$) for corresponding frequencies (GHz) are given by,

$$(-41.8-\delta_1) \leq |H(f)| \leq (-41.8+\delta_1)\,, \quad |f-f_c| \leq 0.512\,, \qquad (3)$$

$$|H(f)| \le (-51.8 + \delta_2)\,, \qquad | f - f_c | = 0.65\,, \qquad (4)$$

$$|H(f)| \le (-54.3 + \delta_3)\,, \qquad | f - f_c | = 0.78\,, \qquad (5)$$

$$|H(f)| \le (-75.8 + \delta_4)\,, \qquad 0.9 \le | f - f_c | \le 2\,. \qquad (6)$$

The enlarged transmitter spectrum mark 620 serves as a rule for designing the indoor enlarged digital lowpass-shaping FIR transmitter filter 514 for the indoor UWB transceiver.

Referring to FIG. 7 is a frequency and impulse response 700 of the indoor digital enlarged lowpass shaping FIR filter based on the enlarged transmitter spectrum mark 620 according to some embodiments. The impulse response 720 of the indoor digital enlarged FIR filter is an odd symmetric and linear phase with a total of 51 filter coefficients. Table 3 lists all the filter coefficients.

Table 3

Coefficients	Value	Coefficients	Value
h[0]	8.4146443275983984e-005	h[-13],h[13]	-3.2214448679624463e-006
h[-1],h[1]	6.6538759917782311e-005	h[-14],h[14]	-1.0826918814367627e-006
h[-2],h[2]	3.4858868895304791e-005	h[-15],h[15]	1.8271797116557857e-006
h[-3],h[3]	4.1937291332765197e-006	h[-16],h[16]	2.9338389172971390e-006
h[-4],h[4]	-1.1315071537226617e-005	h[-17],h[17]	1.4975933707645800e-006
h[-5],h[5]	-1.1106740829476855e-005	h[-18],h[18]	-8.3125861034249542e-007
h[-6],h[6]	-3.9951396057640505e-006	h[-19],h[19]	-1.9498085493385459e-006
h[-7],h[7]	1.7898880674583391e-006	h[-20],h[20]	-1.3114239806658213e-006
h[-8],h[8]	3.8545744226485537e-006	h[-21],h[21]	2.8157753999354317e-008
h[-9],h[9]	3.5424465162252467e-006	h[-22],h[22]	8.5150911646371978e-007
h[-10],h[10]	2.0127906711873520e-006	h[-23],h[23]	8.4195702592509668e-007
h[-11],h[11]	-4.4201040083757460e-007	h[-24],h[24]	4.1121891811157223e-007
h[-12],h[12]	-2.8002950717915257e-006	h[-25],h[25]	-1.9624930527271418e-008

The digital enlarged lowpass-shaping FIR filter 700 may be designed using the least square method with weighting function for each frequency band. Other techniques such as equiripple approximations and windowing may also be used.

The implementation output *y[n]* of the digital FIR filter with 51 odd symmetric coefficients can be expressed as,

$$y[n] = \sum_{k=0}^{50} h[n]x[n-k], \qquad (7)$$

where *h[n]* is a set of the digital FIR filter coefficients as shown in Table 3 and *x[n]* is the digital input signal. Since the digital FIR filter 700 is an odd symmetric coefficient, the above equation (7) can be rewritten as

$$y[n] = \sum_{k=0}^{24} h[n]\big(x[n-k] + x[n-50+k]\big) + h[25]x[n-25]\ . \qquad (8)$$

The equation (8) can be implemented with saving half taps of the computation. The computation complexity of implementing this digital FIR filter 700 in equation (8) is 25 multiplications and 50 additions.

Referring to FIG. 8 is a frequency response 810 of the indoor multiband digital lowpass-shaping FIR filter 800 according to some embodiments. The multi-frequency bands are symmetric with the center frequency. This multiband digital lowpass-shaping FIR filter is created by inserting one zero into the between of two filter coefficients of the

indoor digital enlarged lowpass shaping FIR filter 720. This filter is also referred to as the half band FIR filter. Since the zero coefficients do not have computation with input samples, this indoor multiband digital lowpass-shaping FIR filter has the same as the computation complexities of the digital enlarged lowpass shaping FIR filter 700. Thus, the computation complexity of the indoor multiband digital lowpass shaping FIR filter 810 has also 25 multiplications and 50 additions.

Referring to FIG. 9, which is an enlarged transmitter spectrum mark 920 of the outdoor power spectral density 900 for the use of the outdoor digital enlarged lowpass shaping FIR filter 516 of FIG. 5 according to some embodiments. The enlarged transmitter spectrum mark 920 is a double frequency bandwidth of the transmitter spectrum mask 420 of the outdoor power spectrum density 400 as shown in FIG. 4. The magnitudes (dBm) of the frequency response of the outdoor enlarged transmitter filter with an error of $\pm\delta_i$ (i = 1,2,3,4) for corresponding frequencies (GHz) are given by,

$$(-41.8-\delta_1)\le|H(f)|\le(-41.8+\delta_1)\,,\quad |f-f_c|\le 0.512\,, \tag{3}$$

$$|H(f)|\le(-61.8+\delta_2)\,,\quad |f-f_c|=0.65\,, \tag{4}$$

$$|H(f)|\le(-63.8+\delta_3)\,,\quad |f-f_c|=0.78\,, \tag{5}$$

$$|H(f)|\le(-75.8+\delta_4)\,,\quad 0.9\le|f-f_c|\le 2\,. \tag{6}$$

The outdoor enlarged transmitter spectrum mark 920 serves as a rule for designing an enlarged digital lowpass-shaping transmitter FIR filter for the outdoor UWB transceiver.

Referring to FIG. 10 is a frequency and impulse response 1000 of the outdoor digital enlarged lowpass shaping FIR filter based on the enlarged transmitter spectrum mark 920 according to some embodiments. The impulse response 1020 of the outdoor digital enlarged lowpass shaping FIR filter is an odd symmetric and linear phase with a total of 79 filter coefficients. Table 4 lists all the outdoor filter coefficients.

Table 4

Coefficients	Value	Coefficients	Value
h[0]	7.7822588092588666e-005	h[-20],h[21]	-2.2569595576355567e-006
h[-1],h[1]	6.2706159538768121e-005	h[-21],h[21]	-1.0715363497847361e-006
h[-2],h[2]	3.8005049828479667e-005	h[-22],h[22]	5.2554956470109584e-007
h[-3],h[3]	1.0741444546149776e-005	h[-23],h[23]	1.5115571787722744e-006
h[-4],h[4]	-7.9100957139480000e-006	h[-24],h[24]	1.4266179588856210e-006
h[-5],h[5]	-1.3617274449966842e-005	h[-25],h[25]	4.9809052324633844e-007
h[-6],h[6]	-9.2282250841209486e-006	h[-26],h[26]	-5.9066254728929235e-007
h[-7],h[7]	-1.0206653104093280e-006	h[-27],h[27]	-1.1634171626619683e-006
h[-8],h[8]	5.3549249436944863e-006	h[-28],h[28]	-9.4184481631453274e-007
h[-9],h[9]	6.9957089527049026e-006	h[-29],h[29]	-1.7852893130696073e-007
h[-10],h[10]	4.0766726365610294e-006	h[-30],h[30]	5.8326059832774108e-007
h[-11],h[11]	-8.5812938269354714e-007	h[-31],h[31]	8.7972213415469824e-007
h[-12],h[12]	-4.4365447822251048e-006	h[-32],h[32]	5.9787566708851024e-007
h[-13],h[13]	-4.5122012631596486e-006	h[-33],h[33]	-1.4101683384769071e-010
h[-14],h[14]	-1.5288162010848101e-006	h[-34],h[34]	-5.0807887510975745e-007
h[-15],h[15]	1.9977031110803787e-006	h[-35],h[35]	-6.2137237941119729e-007
h[-16],h[16]	3.5384682976304697e-006	h[-36],h[36]	-3.5990788197097831e-007

h[-17],h[17]	2.4119472792416439e-006	h[-37],h[37]	5.0087020176186946e-008
h[-18],h[18]	-8.0059122411445323e-008	h[-38],h[38]	3.0946891600984111e-007
h[-19],h[19]	-1.9997685118910229e-006	h[-39],h[39]	3.3329123246466921e-007

Referring to FIG. 11 is a frequency response 1110 of the outdoor multiband digital lowpass-shaping FIR filter 1100 according to some embodiments. The multi-frequency bands are symmetric with the center frequency. This multiband digital lowpass-shaping FIR filter 1110 is created by inserting one zero into the between of two filter coefficients of the outdoor digital enlarged lowpass shaping FIR filter 1020. This filter is also referred to as the half band FIR filter. Since the zero coefficients do not have computation with input samples, this outdoor multiband digital lowpass-shaping FIR filter 1110 has the same as the computation complexities of the digital enlarged lowpass shaping FIR filter 1000. Thus, the computation complexity of the outdoor multiband digital FIR lowpass filter 1100 has 39 multiplications and 78 additions.

FIG. 12 is a rejected transmitter image spectrum mark 1220 of the power spectral density 1200 for the use to eliminate the image bands of the indoor and outdoor digital multiband lowpass-shaping FIR filters 810 and 1110 according to some embodiments. The magnitudes (dBm) of the frequency response of the rejected transmitter image

spectrum mask 1220 with an error of $\pm\delta_i$ (i = 1,2) for corresponding frequencies (GHz) are given by,

$$(30.0-\delta_1)\le|H(f)|\le(30+\delta_1)\,,\quad |f-f_c|\le 0.28\,, \qquad (3)$$

$$|H(f)|\le(-18.3+\delta_2)\,,\qquad 1.64\le|f-f_c|\le 2\,. \qquad (6)$$

The rejected transmitter image spectrum mark 1200 serves as a rule for designing a UWB digital rejected filter 522 as shown in FIG. 5.

Referring to FIG. 13 is a frequency and impulse response of the digital rejected lowpass FIR filter 1300 based on the rejected transmitter image spectrum mask 1220 according to some embodiments. The impulse response 1320 of the digital rejected FIR filter is an even symmetric and linear phase with a total of 6 filter coefficients. The computation complexity of this digital filter is 3 multiplications and 5 additions. Table 5 lists all the rejected filter coefficients.

Table 5

Coefficients	Value	Coefficients	Value
h[-1],h[1]	4.3847963307982163e-001	h[-3],h[3]	-3.7781557560682605e-002
h[-2],h[2]	1.0531756617949097e-001		

Referring to FIG. 14 is a frequency response of the indoor combination digital filter 1410 by cascading the indoor digital enlarged lowpass-shaping FIR filter 810 and the digital rejected lowpass FIR filter 1310. The result of this combination digital filter 1410 exactly meet the

requirement of the transmitter spectrum mask 320 of the indoor power spectrum density 300 in FIG. 3.

Referring to FIG. 15 is a frequency response of the outdoor combination digital filter 1510 by cascading the outdoor digital enlarged lowpass-shaping FIR filter 1110 and the digital rejected lowpass FIR filter 1310. The result of this outdoor combination digital filter 1510 exactly meet the requirement of the transmitter spectrum mask 420 of the outdoor power spectrum density 400 in FIG. 4.

FIG. 16 is an indoor output of multi-carrier frequency spectrums (dBm) 1600 including 11 transmitter channel spectrums 1620A-1620K along with the indoor FCC emission limitation 1610 according to some embodiments. Each channel frequency bandwidth is 650 MHz and is fitted under the indoor FCC emission limitation 1610 with different carrier frequencies. The detail positions of each transmitter channel spectrums (dBm) along with the center, lower and upper frequencies (GHz) as well as channel frequency bandwidth (MHz) are listed in Table 6.

Table 6

Label of transmitter channel frequency spectrums	Center Frequency (GHz)	Lower Frequency (GHz)	Upper Frequency (GHz)	Frequency Bandwidth (MHz)
1620A	3.45	3.125	3.775	650
1620B	4.10	3.775	4.425	650
1620C	4.75	4.425	5.075	650
1620D	5.40	5.075	5.725	650
1620E	6.05	5.725	6.375	650
1620F	6.70	6.375	7.025	650
1620G	7.35	7.025	7.675	650
1620H	8.00	7.675	8.325	650
1620I	8.65	8.325	8.975	650
1620J	9.30	8.975	9.625	650
1620K	9.95	9.625	10.275	650

FIG. 17 is an outdoor output of multi-carrier frequency spectrums (dBm) 1700 including 11 transmitter channel spectrums 1720A-1720K along with the outdoor FCC emission limitation 1610 according to some embodiments. Each channel frequency bandwidth is 650 MHz and is fitted under the outdoor FCC emission limitation 1610 with different carrier frequencies. The detail positions of each transmitter channel spectrums (dBm) along with the center, lower and upper frequencies (GHz) as well as channel

frequency bandwidth (MHz) are the same as listed in Table 6.

FIG. 18 is a block diagram of showing dual-mode architecture of the digital transmitter lowpass-shaping FIR filter for indoor and outdoor operation according to some embodiments. Six separate memory banks 1812, 1814, 1816, 1830, 1834A and 1834B are used. Four separated memory banks 1814, 1816, 1834A and 1834B, which may be ROM for single-purpose filters or RAM for programmable filters, are dedicated to the filter coefficients, fixed in value during operation. The memory bank 1814 contains the indoor digital enlarged lowpass-shaping FIR filter coefficients 720. The memory bank 1816 includes the outdoor digital enlarged lowpass-shaping FIR filter coefficients 1020. The memory banks 1834A and 1834B store even and odd filter coefficients of the digital rejected lowpass FIR filter 1320, respectively. The other memory banks 1812 and 1830 are data memory with RAM to set aside for the input samples. The data memory banks 1812 and 1830 act as a circular buffer.

The input samples are passed through a pre-addition 1824 to perform the symmetric addition operation. The output samples of the pre-addition 1824 are stored into the data memory bank 1812 with a circular buffer by controlling of the circular counter 1810. The selectable unit 1822 controls a MUX unit 1820 to select either the memory bank

1814 or the memory bank 1816 with a counter modular 1818. The selected memory bank, either the memory bank 1814 or the memory bank 1816, operates with the input samples in the data memory bank 1812 by using the MAC unit 1826 to produce the filter output y[n]. Then the output samples y[n] are stored into the data memory bank 1830. The switch 1840 connects to the position 1838A when n = 0, 2, 4, …, and connects to the position 1838B when n = 1, 3, 5, …. Thus, the input samples of the data memory bank 1830 with the circular counter 1832 are multiplied and accumulated with the memory banks 1834A and 1834B of the even and odd digital rejected FIR filter coefficients with counter modular 1836 to produce the output by using the MAC unit 1828.

Referring to FIG. 19, which is a detailed block diagram 1900 of showing one embodiment of the pre-addition unit 1824 of the present invention. The units 1910A-1910Y and units 1920A-1920Y are called as the one sample delay unit. There are a total of 50 sample delay units. The unit 1930A-1930Y is referred to as the addition operation unit. There are a total of 25 addition operation units. The input samples x[n] are passed through the delay and addition operation units to produce the output samples as follows:

$q[n-k]=x[n-k]+x[n-50+k]$, for k=0, 1, 2, …, 24.

$q[n-k]=x[n-k]$, for k =25.

Then, the switch 1950 sequentially connects to the positions 1940A-1940Y until the last sample is finished. Thus, the pre-addition unit 1900 may achieve the pre-addition calculation for the input samples that are used to reduce the computations when the output samples q[n] are multiplied with the odd symmetric filter coefficients.

Referring to FIG. 20, which is a detailed block diagram 2000 of showing the filter coefficient memory banks and the data memory banks. The memory banks 1814 and 1816 contain the indoor digital enlarged lowpass-shaping FIR filter coefficients 720 and the outdoor digital enlarged lowpass-shaping FIR filter coefficients 1020, with the counter modular. The data memory bank 1812 contains the input data samples, with the circular counter. The memory banks 1834A and 1834B contain the even and odd filter coefficients of the digital rejected FIR filter 1320, with the counter modular. The data memory bank 1830 contains the input data samples, with the circular counter.

FIG. 21 is a block diagram of the dual-mode UWB communication receiver 2100 of the indoor and outdoor operation according to some embodiments. A low noise amplifier (LNA) 2160, which is coupled to a multichannel-based multi-carrier down converter 2162, receives the UWB signals from an antenna. The output of LNA 2160 is passed through the multichannel-based multi-carrier down converter 2162 to produce the baseband signal for an A/D converter

2164. The multichannel control 2170 and synchronization and time control 2168 restrain the multichannel-based multi-carrier down converter 2162. The bandlimited UWB analog signals are then sampled and quantized by using an A/D converter 2164, with the sampling frequency rate of 720 MHz. The digital signals of the output of the A/D converter 2164 are filtered by using an indoor or outdoor dual-mode digital FIR receiver lowpass FIR filter 2166 to remove the out of band signals with controlling from the synchronization and time control 2168. The output data from the dual-mode digital receiver lowpass FIR filter 2166 is used for a rake receiver 2174. The channel estimator 2172 is used to estimate the channel phase and frequency that are passed into the rake receiver 2174. The rake receiver 2174 calculates the correlation between the received UWB signals and the channel spread sequences, which are provided by using the PN sequence look-up table 2182, and performs coherent combination. The output of the rake receiver 2174 is passed to an equalizer 2176, which also receives the information from the channel estimator 2172, to eliminate inter-symbol interference (ISI) and inter-channel interference (ICI). Then, the output of the equalizer 2176 produces the signals for a de-spreading of PN sequence and de-mapping 2178 to form the UWB signals of symbol rate at 446.875 Msps. The symbol data is de-interleaved by using a block de-interleaver 2180. Thus, the

output data of the block de-interleaver 2180 is used for the Viterbi decoder 2184 to decode the encoded data and to produce the information data bits at 223.4375 Mbps.

Referring to FIG. 22, which is a detailed block diagram 2200 of showing one embodiment of the dual-mode digital receiver FIR filter 2166 of the present invention. During the indoor UWB receiver mode, a switch 2212 connects to a position 2210A and a switch 2220 connects to a position 2218A. Thus, the dual-mode digital receiver FIR filter is used for the indoor UWB transceiver. During the outdoor UWB receiver mode, the switch 2212 connects to the position 2210B and the switch 2220 connects to the position 2218B. In this case, the dual-mode digital receiver FIR filter is used for the outdoor UWB transceiver.

FIG. 23 is a receiver spectrum mask 2320 of the indoor UWB power spectrum density 2300 according to some embodiments. The magnitudes (dBm) of the frequency response with an error of $\pm\delta_i$ (i = 1,2,3) for corresponding frequencies (MHz) are given by,

$$(-41.3-\delta_1) \le |H(f)| \le (-41.3+\delta_1)\,, \quad |f-f_c| \le 260\,, \tag{3}$$

$$|H(f)| \le (-51.3+\delta_2)\,, \quad |f-f_c| = 325\,, \tag{4}$$

$$|H(f)| \le (-75.3+\delta_3)\,, \quad 340 \le |f-f_c| \le 360\,. \tag{6}$$

The indoor receiver spectrum mark 2320 serves as a rule of designing a digital receiver FIR lowpass filter for the indoor UWB transceiver.

Referring to FIG. 24 is a frequency and impulse response 2400 of the indoor digital receiver FIR filter according to some embodiments. The impulse response 2420 of the indoor digital receiver FIR filter is an odd symmetric and linear phase with a total of 39 filter coefficients. Thus, the computation complexity of the indoor digital receiver FIR lowpass filter 2420 has 19 multiplications and 38 additions. Table 7 lists all the indoor filter coefficients.

Table 7

Coefficients	Value	Coefficients	Value
h[0]	2.2711340594043999e-004	h[-10],h[10]	-2.2153543980269178e-006
h[-1],h[1]	4.2079839082892464e-005	h[-11],h[11]	1.4968638128566580e-006
h[-2],h[2]	-3.3790355985451722e-005	h[-12],h[12]	-1.1830181905096312e-007
h[-3],h[3]	2.2800600739704647e-005	h[-13],h[13]	-1.1477807925811817e-006
h[-4],h[4]	-1.2124392687415319e-005	h[-14],h[14]	1.7805637473547527e-006
h[-5],h[5]	4.2180879116521021e-006	h[-15],h[15]	-1.6754436913295128e-006
h[-6],h[6]	-1.1365258519547985e-007	h[-16],h[16]	1.1620898376791844e-006
h[-7],h[7]	-6.3388913197064538e-007	h[-17],h[17]	-6.5665355826769077e-007
h[-8],h[8]	-4.7720212586639754e-007	h[-18],h[18]	4.6288213011845176e-007
h[-9],h[9]	1.8041014288773825e-006	h[-19],h[19]	-5.6171814558031744e-007

FIG. 25 is a receiver spectrum mask 2520 of the outdoor UWB power spectrum density 2500 according to some embodiments. The magnitudes (dBm) of the frequency response with an error of $\pm\delta_i$ (i = 1,2,3) for corresponding frequencies (MHz) are given by,

$$(-41.3-\delta_1) \le |H(f)| \le (-41.3+\delta_1)\,, \quad |f-f_c| \le 260\,, \qquad (3)$$

$$|H(f)| \le (-61.3 + \delta_2), \qquad |f - f_c| = 325, \qquad (4)$$

$$|H(f)| \le (-75.3 + \delta_3), \qquad 340 \le |f - f_c| \le 360. \qquad (6)$$

The outdoor receiver spectrum mark 2520 serves as a rule of designing a digital receiver FIR lowpass filter for the outdoor UWB transceiver.

Referring to FIG. 26 is a frequency and impulse response 2600 of the outdoor digital receiver FIR filter according to some embodiments. The impulse response 2620 of the outdoor digital receiver FIR filter is an odd symmetric and linear phase with a total of 39 filter coefficients. Thus, the computation complexity of the outdoor digital receiver FIR lowpass filter 2620 has 19 multiplications and 38 additions. Table 8 lists all the outdoor filter coefficients.

Table 8

Coefficients	Value	Coefficients	Value
h[0]	2.1659294012222948e-004	h[-10],h[10]	-3.3766314744991133e-006
h[-1],h[1]	5.1010900807138207e-005	h[-11],h[11]	2.5193334120019112e-006
h[-2],h[2]	-3.8577600935448179e-005	h[-12],h[12]	-5.1162314715269453e-007
h[-3],h[3]	2.2434916624067460e-005	h[-13],h[13]	-1.2437956638809358e-006
h[-4],h[4]	-7.4313753473442792e-006	h[-14],h[14]	1.8528143860654983e-006
h[-5],h[5]	-2.6722025657057541e-006	h[-15],h[15]	-1.2782534000936749e-006
h[-6],h[6]	6.5007896593555187e-006	h[-16],h[16]	1.7904952933954231e-007
h[-7],h[7]	-5.1746497965425773e-006	h[-17],h[17]	6.4369115613109251e-007
h[-8],h[8]	1.3955837238699170e-006	h[-18],h[18]	-7.2838193152203750e-007
h[-9],h[9]	2.0273922562789145e-006	h[-19],h[19]	1.7807071893959747e-007

FIG. 27 is a block diagram of showing dual-mode architecture of the digital receiver FIR filter for the indoor and outdoor operation according to some embodiments. Three separate memory banks 2712, 2714 and 2716 are used. Two separated memory banks 2714 and 2716, which may be ROM for single-purpose filters or RAM for programmable filters, are dedicated to the filter coefficients, fixed in value during a operation. The memory bank 2714 contains the indoor digital receiver FIR filter coefficients 2420. The memory bank 2716 includes the outdoor digital receiver FIR filter coefficients 2620. The other memory bank 2712 is data memory with RAM to set aside for the input samples. The data memory bank 2712 act as a circular buffer.

The input samples are passed through a pre-addition unit 2724 to perform the symmetric addition operation. The output samples of the pre-addition 2724 are stored into the data memory bank 2712 with a circular buffer by controlling of the circular counter 2710. The selectable unit 2722 controls the MUX unit 2720 to select either the memory bank 2714 or the memory bank 2716 with the counter modular 2718. The selected memory bank, either the memory bank 2714 or the memory bank 2716, operates with the input samples in the data memory bank 2712 by using the MAC unit 2726 to produce the filter output.

Referring to FIG. 28, which is a detailed block diagram 2800 of showing one embodiment of the pre-addition

unit 2724 of the present invention. The units 2810A-2810T and units 2820A-2820T are called as the one sample delay unit. There are a total of 38 sample delay units. The units 2830A-2830T are referred to as the addition operation unit. There are a total of 19 addition operation units. The input samples x[n] are passed through the delay and addition operation units to produce the output samples as follows:

$q[n-k]=x[n-k]+x[n-50+k]$, for k=0, 1, 2, …, 18.

$q[n-k]=x[n-k]$, for k =19.

Then, the switch 2850 sequentially connects to the positions 2840A-2840T until the last sample is finished. Thus, the pre-addition unit 2800 may achieve the pre-addition calculation for the input samples that are used to reduce the computations when the output samples q[n] are multiplied with the odd symmetric filter coefficients.

Referring to FIG. 29, which is a detailed block diagram 2900 of showing the filter coefficient memory banks and the data memory banks. The memory banks 2714 and 2716 contain the indoor digital receiver filter coefficients 2420 and the outdoor digital receiver filter coefficients 2620, with the counter modular. The data memory bank 2712 contains the input data samples, with the circular counter.

FIG. 30 is a block flowchart of showing the dual-mode indoor and outdoor UWB transceiver with transmitter and receiver modes according to some embodiments. The indoor and outdoor UWB 3010 is connected with the transmitter and